Nonmagnetic UHV Optical Viewports

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Abstract—**Many atomic physics and frequency metrology applications require nonmagnetic optical viewports for ultra high vacuum (UHV) chambers. We have refined two techniques for producing specialized UHV optical viewports. The first is a weld-in window cell made by brazing an optical blank into a thin weld collar. The second is a mechanical sealing method that relies on crushing a series of thin copper knife-edges.**

I. Introduction

A wide variety of laboratory experimentation requires optical viewports in UHV chambers. Some of these situations also require that the viewport and chamber be nonmagnetic. This precludes the use of common techniques using magnetic materials that are commercially available.

In our work on the design of atomic fountain clock vacuum chambers, we have pursued two weld-in designs, and a mechanically sealed design. We will discuss our designs and results in producing these viewports.

II. Weld-In Designs

A. Motivation

We wanted to develop window system with a large ratio of optical clear aperture to total area. A weld-in window design eliminates the demountable bolt circle of the standard 2.75" UHV ConFlat [1] and replaces it with a small weld, allowing the construction of compact, monolithic vacuum chambers with good optical access.

Another priority was producing a robust vacuum system having many windows that could withstand repeated high temperature bakeout cycles to condition the vacuum system. Indium or lead solder has be used for mechanically sealing windows joints to vacuum chambers [2] or brazing together weld-in windows cells [3], but the bakeout temperature is limited by the melting point (157 °C for Indium and ~180 °C for lead solder) and can fail at even lower temperatures, making it difficult to achieve UHV. These considerations drove us towards designs that used high temperature brazes in the assembly of the window cells. In addition, the use of high temperature brazes allows reliable application of optical coatings after brazing.

B. High Temperature Design

The desire to use high temperature brazes for assembling the windows, and our requirement that the window assembly be non-magnetic limited our choices of materials. We chose titanium (CP grade 2) for our weld collars based on a series of welding tests with nonmagnetic materials (see section II.D).

The choices of titanium and high temperature brazes limited our choices of window materials. Sapphire and titanium can be brazed with copper-silver-titanium (or closely related) brazes. This type of braze uses a small addition of titanium to a copper-silver eutectic to enhance wetting to ceramics and metals other than copper and silver.

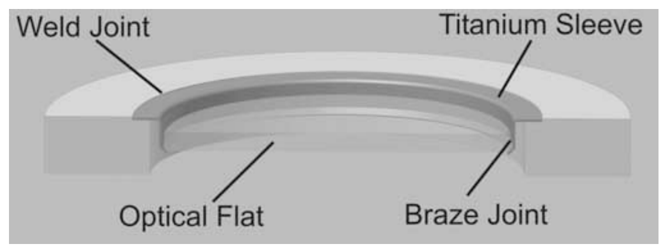

Figure 1. Cross section of the weld-in window cell.

In our design, we use a thin 0.25 mm (0.010") thick titanium sleeve that flexes to provide some relief for the stress arising from difference in thermal expansion between a sapphire optical flat and the titanium sleeve. The clear aperture of the 2.0 mm (0.080") thick window is 35.6 mm (1.4"). The outer lip of the weld collar is 44.5 mm (1.75") in diameter. The assembly is only 3.9 mm (0.152") thick and requires a clear bore of 40.6 mm (1.6") in the vacuum chamber.

Our sapphire optical flats where cut with the c-axis perpendicular to the face, so no birefringence effects of sapphire were noticeable. The low profile and minimal gap between the sleeve lip and the optical flat ensures a minimal shadowing effect when an optical coating is applied to the sapphire after having been brazed into the titanium sleeve.

These window cells are fabricated commercially and bakeable to 450 °C. They are welded into our vacuum chambers and produce final assemblies that do not show any

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14. ABSTRACT
Many atomic physics and frequency metrology applications require nonmagnetic optical viewports for ultra high vacuum (UHV) chambers. We have refined two techniques for producing specialized UHV optical viewports. The first is a weld-in window cell made by brazing an optical blank into a thin weld collar. The second is a mechanical sealing method that relies on crushing a series of thin copper knife-edges.

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leaks at the 6×10^{-11} T-l/s level in two parts with up to 10 windows each. We have recently learned of similar work for application to a flight prototype ion clock [3].

Figure 2. High-temperature weld-in window cell. The cell is shown both before welding, and welded into a test flange. The weld collar and flange are titanium, and the window material is sapphire. Included with permission of MPF products, incooperated[1].

C. Low Temperature Design

In parallel to our development of high temperature weld-in windows, we pursued a design with a lower temperature solder to join the window to the weld collar. This design closely follows the work of JPL for space hardware [3].

These viewports were produced with fused silica windows and titanium collars. Optical coatings were applied to the windows before soldering into the weld collars. The lower temperature solder limits bakeout temperatures to less than 180 °C. The dimensions of the windows were the same as the high temperature versions with the exception of the thickness, which was 6.1 mm (0.24"). When welded into a vacuum chamber, they also did not show any leaks at the 6×10^{-11} T-l/s level for single windows. Because of our success with the high temperature design, we did not use the low temperature design in our final vacuum chambers.

D. Welding

Welding tests were performed using various nonmagnetic material combinations. Titanium-to-titanium welds proved by far the easiest to work with. The weld joint can be seen in Fig. 1 where the 0.25 mm (0.010") lip of the weld-in window flange is made to fit into a machined weld-port on the vacuum chamber of depth 0.38 mm (0.015") and slightly larger OD. We monitored the temperature within 5 mm of an e-beam weld bead and saw temperatures that stayed below 40 °C for a machined titanium test sleeve and titanium weld-port.

For other material combinations more welding power was required to make a leak-tight seal and resulted in higher temperatures including stainless to stainless (~60 °C), copper to stainless (~75 °C) and copper to copper (~100 °C). Titanium cannot be welded to either stainless or to copper.

We found CNC laser welding to be best for joining the thin lip of the titanium window collar to the vacuum chamber as it minimizes the heat and stress which can cause window failure. Laser welding also allows for better control of the weld location and heating than e-beam welding. This was quite useful for our weld-in window design where the weld joint was very close to the braze joint. Fit-up of the brazed titanium sleeve to the vacuum chamber was another important issue, as a poor fit-up requires more welding power. With a titanium sleeve lip OD tolerance of 0.08 mm (0.003") and a flatness specification of less than 0.13 mm (0.005"), we had high success rate.

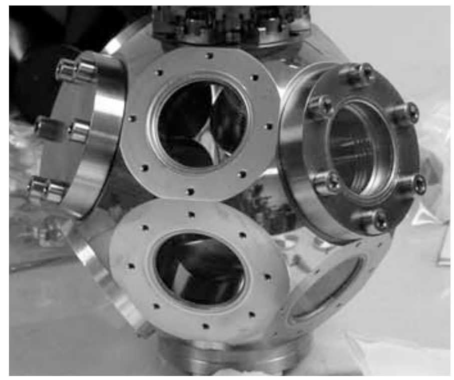

Figure 3. Picture of a titanium vacuum chamber with several high temperature weld-in windows. Three of the visible windows are welded directly into the chamber, with a fourth welded into a titanium ConFlat flange.

E. Lessons Learned

We tried several combinations of nonmagnetic materials that we would not recommend. We were able to produce windows with copper collars using a high temperature braze. While these windows were leak tight before welding, the welding temperatures required to make good joints to either copper or stainless steel vacuum chambers were too high. Welding produced small fractures in the windows or the braze material near the window edge far too often for us to use these materials in our final designs. We tried but were unable to produce windows with stainless steel collars with our low profile,high temperature braze design.

III. Mechanically Sealed Viewports

We have also developed a nonmagnetic window system using a mechanical seal that is inspired by the work of Kasevich [4]. Our sealing design provides low, symmetric stresses to both sides of an optical flat and is essentially as easy as sealing any conventional ConFlat blank.

[1] The U.S. Naval Observatory does not endorse any commercial product nor does USNO permit any use of this document for marketing or advertising.

A. Gasket Design and Construction

The key element in this design is a copper gasket with identical, 0.38 mm (0.015”) tall knife-edges with a 60 degree included angle protruding from the top and bottom of the gasket. The gasket is compressed between flat surfaces so as to crush each knife-edge by 0.12 mm (0.005”). A cross section of the gasket is shown in Fig. 4.

In the Kasevich design a similar knife-edge is machined into the top of the copper gasket, but the bottom remains flat, meant to be pressed into a standard ConFlat knife-edge having an inclination angle of 20 degrees. The resulting nonsymmetrical crushing forces required to make the seal can cause the window to crack. In our design all force to crush a knife-edge is transmitted through another identical knife-edge producing low and very symmetric stresses on the window. Using this method, no windows were broken in our sealing tests.

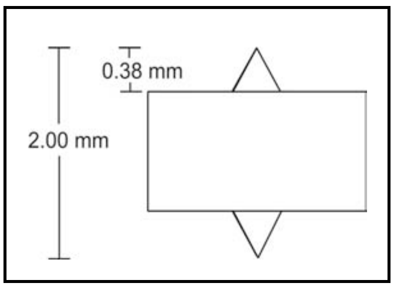

Figure 4. Demountable copper gasket cross section. The two knife edges are crushed against flat surfaces to make the vacuum seal.

After sealing and bakeout, we examined several of the copper gaskets. Gaskets were examined by eye, with a loupe, and in a shadowgraph after sectioning with electric discharge machining. The flat areas on the top of the knife edges were uniform, and varied by less than 0.03 mm (0.001”) in width for a given knife edge, indicating uniform pressure around the circumference of the seal. The cross section views showed 0.10 mm to 0.15 mm (0.004” to 0.006”) flat areas, with the sides of the knife-edge bowed out to form convex sides. There was no qualitative difference between the baked and unbaked gaskets.

B. Low Profile, Large Aparature Design

A reasonably aggressive design gives a low profile 8.5 mm (0.335”) height window cap with a 44.5 mm (1.75”) clear aperture when using thin 3.2 mm (0.125”) windows. The recess in the window cap provides the needed 0.51 mm (0.020”) crush to the gaskets when bolted to the seat. This design uses a 50 mm (2”) diameter window and fits onto a standard 2.75” CF flange bolt circle.

In addition, the gaskets have a 48 mm (1.90”) outer diameter, which matches the outer diameter of the CF gasket. This would allow the simple retrofitting of a CF flange into a large clear aperture demountable window. A cross section of this design can be seen in Fig. 5. The assembly bolts down with minimal force and has sealed reliably on every attempt.

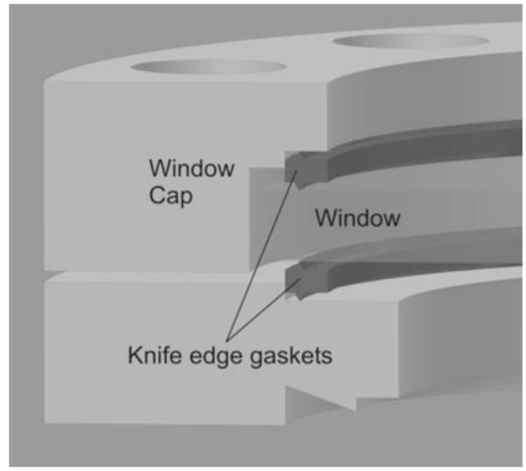

Figure 5. Cross section of a mechanically sealed window design. The vacuum seal is created by crushing the knife edges on the copper gaskets

C. Mechanical Seal Performance

The mechanically sealed viewports have shown robust performance and easy assembly. We have assembled and tested several viewports with thick windows, using feeler gauges to set the amount of crush on the gaskets. We have also tested designs like shown in the previous subsection where the window cap is bolted firmly to the vacuum chamber. We have made successful viewports with BK7, fused silica, sapphire, and silicon windows. We broke no windows, and all survived bakeouts of at least 250 ^{o}C without leaking. We tested the windows for leaks by creating a helium atmosphere on the outside of the window and looking with a residual gas analyzer for helium intrusion at UHV. All designs and windows showed no leaks at the $6x10^{-11}$ T-l/s level.

We also tested these seals using both stainless steel and titanium flanges and compared them to standard metal to metal ConFlat seals. We were surprised to find that our mechanical window sealing method was able to withstand higher bakeout temperatures than standard ConFlat seals when using titanium flanges. This was true when comparing to ConFlat flanges that mated titanium to titanium (maximum bakeout temperature is 180 ^{o}C with a 2.75” flange) as well as stainless steel mated to titanium.

The coefficients of expansion of stainless steel and copper are close, allowing ConFlat bakeout temperatures up to 275 ^{o}C or more. However, with the titanium ConFlat flanges, the difference in thermal expansion rate with copper is significant causing leaks to occur after the temperature cycle. Our mechanically sealed window design seems to provide a better stress release mechanism to compensate for the different thermal expansion rates. No leaks were observed for our method whether using either stainless or titanium.

Figure 6. Picture of a sapphire window with knife edge gaskets resting on a vacuum flange. These parts are those shown in Fig. 5 with the exception of the window cap. There is a third copper gasket leaning against the whole assembly.

IV. CONCLUSIONS

We have refined two techniques for producing nonmagnetic UHV viewports. The first is a weld-in window cell made by brazing an optical blank into a thin weld collar. The second is a mechanically sealed method that relies on crushing a series of thin copper knife-edges. Our efforts have culminated in a commercially produced weld-in window design that is bakeable to high temperatures (450 ^{o}C), and a mechanical window sealing method that reliably seals as easily as a standard ConFlat blank and out-performs ConFlat seals when using titanium flanges.

ACKNOWLEDGMENT

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[1] "ConFlat" is a trademark of Varian Corp., and implies no commercial endorsement by USNO or the federal government.

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